SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The use of the 4-GHz (3700- to 4200-MHz) band by earth stations in the fixed-satellite service has increased rapidly in recent years due to the growth in the number of earth stations associated with broadcasting, such as television receive-only (TVRO) and audio distribution systems. As the transition to earth stations associated with broadcasting has evolved, there have been several reported cases of interference to 4-GHz earth stations caused by radar stations operating in the bands below 3700 MHz. The potential for interference from high-power radars could escalate as broadcasting systems continue to proliferate and to rapidly migrate towards digital-type systems. The following are conclusions and recommendations based on findings contained in this report.

6.2 GENERAL CONCLUSIONS

1. Interference from both Government and non-Government radars to 4-GHz earth stations has been documented.

2. Interference from radar stations to 4-GHz earth stations can occur even if all current NTIA standards applicable to radar transmitters and FCC standards applicable to earth station receiver systems are satisfied.

3. NTIA measurements and tests have shown that the interference from radars to 4-GHz receive-only earth stations can occur as a result of two interference coupling mechanisms:

    a) receiver front-end overload from the radar center-frequency (fundamental) emissions causing gain compression (reduction in desired signal level) in the earth station front-end low-noise amplifier; the compression occurs not just at the radar fundamental frequency, but also across the entire response band of the earth station front-end

    b) radar transmitter spurious emissions in the 3700- to 4200-MHz band, which cause degradation by increasing the C/I ratio at the frequency or frequencies used by the earth station.

4. Resolution and mitigation of interference from radars to 4-GHz fixed-satellite earth stations depends upon the ability to determine the interference coupling mechanism. The interference coupling mechanism can generally be substantiated by installing a 3700- to 4200-MHz bandpass filter a<u>head</u> of the low-noise amplifier. If interference continues, the test and measurement procedures contained in Section 5 of this report should be used to determine the interference coupling mechanism.

6.3 SPECIFIC CONCLUSIONS

Spectrum Policy and Regulations

The following are conclusions related to spectrum policy and regulations associated with compatibility between stations.

1. There are no interference immunity standards pertaining to non-Government 4-GHz earth stations. The FCC generally declines to establish effective receiver system spectrum standards and lets the marketplace reach a consensus on receiver design.

2. For Federal radar stations, the responsibility for mitigating interference due to radar transmitter spurious emissions is dependent upon radar station compliance with appropriate spectrum standards and which system (radar or earth station) existed first. (NTIA Manual Section 2.3.7).

Earth Station Receiver Front-end Overload

The following are conclusions related to radar interference cause by earth station receiver front-end overload.

1. The desired signal level received by earth stations is very low, thus requiring low-noise amplifiers (LNA/LNB/LNC) of 50-65 dB gain in the earth station RF front-ends.

2. Low-noise amplifiers (LNA/LNB/LNC) used in some earth stations produce gain over 40 percent of the spectrum below 5 GHz (2.8-4.8 GHz). This makes the receiver systems extremely susceptible to interference from high-powered radar systems operating in adjacent bands and in accordance with regulations.

3. Radar signal peak power levels at which receiver front-end overload occurs are a function of the gain of the low-noise preamplifier (LNA/LNB/LNC) used in the earth station. Since the gain of preamplifiers used by earth stations in this band range between 50-65 dB, the gain compression threshold may occur at radar signal levels at the input to the LNA/LNB/LNC of -55 to -40 dBm.

4. Radar interference due to earth station receiver front-end overload can be mitigated by inserting an RF bandpass (preselector) filter <u>ahead</u> of the low-noise amplifier. Measured in-band insertion losses of RF preselector filters are typically 0.5 dB.

5. Earth station receiver front-end preamplifiers that incorporate mixer/downconverters (LNB and LNC devices) are more likely to generate undesired product responses than low-noise preamplifiers which do not incorporate downconversion. Such responses may cause interference with the desired signal, and may also be mistaken for radar spurious emissions.

6. Earth station receiver front-end preamplifiers that incorporate built-in preselection showed reduced susceptibility to front-end overload from radar-like signals in the 2700-3500 MHz portion of the spectrum, but were still susceptible to overload by strong signals in the frequency range of 3500-3700 MHz. Because some radar systems operate in the 3500-3700 MHz portion of the spectrum, the use of such preamplifiers reduces but does not eliminate the possibility of front-end overload in such devices.

7. The gain compression interval of front-end preamplifiers ranges from less than 1 μs to approximately 900 μs. The compression interval depends upon the characteristics of the preamplifier and the amount of gain compression which has occurred. Devices incorporating mixer/downconverters (LNB/LNC) exhibited recovery intervals that were about two orders of magnitude shorter than the LNA recovery intervals.

8. The separation distance required to preclude receiver front-end overload from airborne radars in bands adjacent to the 4-GHz band is several hundred km even at off-axis angles greater than 10 degrees. For surface radars, receiver front-end overload interference may occur at ranges of 60 km for a few degrees off-axis to less than 40 km for off-axis angles greater than 30 degrees.

Radar Transmitter Spurious Emissions

The following are conclusions related to interference to earth stations caused by radar transmitter spurious emissions.

1. The predominant factor that governs the level of spurious emissions from radars is the transmitter output device.

2. When radar transmitter spurious emissions are identified as the interference source, then the additional task of identification of the radar must be performed. Measurement procedures for obtaining radar transmitter characteristics that will assist in such identification are contained in Section 5.

3. Interference mitigation options for radars to reduce radar transmitter spurious emission coupling include inserting an RF filter after the radar output device. However, in cases where radars use antenna phased array techniques, such filters cannot be installed.

4. Interference mitigation options for earth stations to reduce radar transmitter spurious emissions coupling include the use of shrouded antenna dishes and careful site selection.

5. There have been no substantiated cases of radar spurious emission interference from airborne radars to 4-GHz earth stations. All airborne radars in the 2700-3700 MHz range use klystron output tubes which have very low spurious emission levels (approximately -110 to -120 dBc).

6. The separation distance required to preclude radar transmitter spurious emission interference ranges from several hundred km at off-axis angles of less than 5 degrees to less than 50 km for off-axis angles greater than 30 degrees.

6.4 RECOMMENDATIONS

1. **NTIA should hold discussions with major earth station manufacturers and system integrators to recommend that RF front-end preselection filters be included as a standard part of new 4-GHz earth station installations; the purpose of the preselectors would be to preclude receiver front-end overload due to strong adjacent-band radar signals. This practice would enhance compatibility between radars in the 2700- to 3700-MHz portion of the spectrum and fixed-satellite earth stations in the 3700- to 4200-MHz portion of the spectrum.**

2. **NTIA should hold discussions with manufacturers of LNAs, LNBs and LNCS to recommend that they incorporate very sharp preselector filters (similar to preselector filter characteristics shown in Figure 11) in those devices.**

3. **In response to reported cases of radar interference to 4-GHz earth stations, NTIA recommends that the following action(s) be taken:**

   a) **install a 3700- to 4200-MHz bandpass filter (preselector) <u>ahead</u> of the low-noise preamplifier**

   b) **if the interference continues, use the procedures described in Section 5 to identify the interference coupling mechanism and, if the interference is identified as radar transmitter spurious emissions in the 4-GHz band, identify the radar emission parameters (i.e., center frequency, scan pattern, scan rate, pulse repetition rate, pulse width).**

4. **NTIA should inform appropriate industry associations and service providers of the findings of this report to work towards the development of possible solutions to the interference problem.**

5. **NTIA should submit the measurement procedures described in Section 5 to the International Telecommunication Union, Radiocommunication Sector (ITU-R), to aid administrations in determining the interference coupling mechanism(s) when radar interference to fixed-satellite earth stations occurs.**